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(71) Applicant: SHARP KABUSHIKI KAISHA
Osaka 545 (JP)

(72) Inventors:
- Davis, Gillian
  Abingdon, Oxon., OX14 1LZ (GB)
- Walsh, Kathryn
  Caversham, Reading (GB)

(74) Representative: Pearce, Anthony Richmond
MARKS & CLERK,
Alpha Tower,
Suffolk Street Queensway
Birmingham B1 1TT (GB)

(54) Illumination system and display device

(57) An illumination system comprises a polarised light source (10, 12, 14, 16) which emits circularly polarised light of a particular handedness and a cholesteric filter (18) having a region arranged to transmit circularly polarised light falling within a first wavelength band and to reflect other wavelengths of circularly polarised light. A reflector (12) redirects the reflected light back towards the cholesteric filter (18). The cholesteric filter (18) may comprise a first layer (20) having portions which reflect red, green and blue light while transmitting other colours, and a second layer (22) identical to the first layer (20) but out of alignment therewith so that each region of the filter (18) transmits only one colour of light, the other colours being reflected.

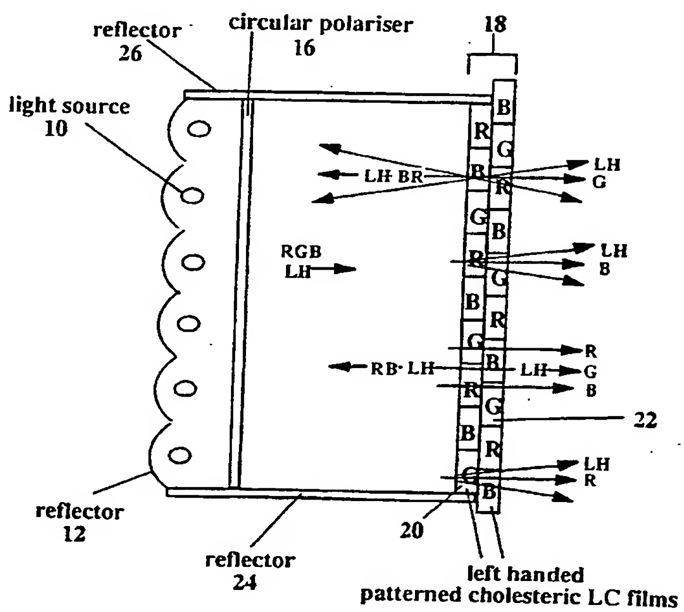

Figure 1

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Description

This invention relates to an illumination system, and to a display device.

Colour liquid crystal display devices commonly comprise a light source and a liquid crystal display including a plurality of picture elements, each of which aligned with one of the colour filter elements of an array of such filter elements. Each of the colour filter elements transmits light falling within a particular wavelength band and absorbs all other light incident thereon. In devices arranged to transmit red, green and blue light, the filters absorb a large proportion of the light incident thereon. It is usual for the filter elements to be integral with the display, ie between the glass substrates thereof.

In addition, liquid crystal display devices include polarising films which are arranged to transmit one polarisation of light. These films therefore further reduce the intensity of light incident upon the liquid crystal display.

GB 2260203 describes a device in which a holographic element is used to filter the light incident upon a liquid crystal display, the holographic element comprising a plurality of regions, each of which is arranged to diffract light of a particular wavelength or wavelength band out of a lightguide, and to have no affect on light falling outside of that band. The use of holographic elements is inconvenient in that they are difficult to mass produce.

It is known, for example from US 5235443, US 5 295 009 and a paper in the Japanese Journal of Applied Physics 29, 1974, 1990, that cholesteric liquid crystal polymers can be used as colour filters and as circular polarisers. For instance, US 5 235 443 and US 5 295 009 disclose the use of cholesteric liquid crystal polymers for polarising monochromatic light. Unpolarised light from a monochromatic light source is divided into left- and right-handed circularly polarised light. Light of one polarisation is transmitted. Light of the orthogonal polarisation has its polarisation reversed and is reflected back through the polariser so as to provide light having a single handedness of circular polarisation.

US 5 325 218 and EP 0 634 674 also disclose the use of cholesteric elements as polarisers.

US 5 267 060 discloses a colour matrix display having a holographic optical element which acts as a colour matrix reflective filter. Each pixel of the filter transmits light of one colour and reflects light of other colours. The reflected light is returned to a reflective light assembly for reuse. In addition, US 5221982 describes a thin colour pixelated light source using cholesteric materials for use in a backlight of a colour liquid crystal display. The device comprises a laminate of layers of cholesteric material having different optical properties, the laminate being sliced at an angle of 45° and polished to form a complex colour pixelated element. Such a construction is difficult to produce.

According to a first aspect of the present invention there is provided an illumination system as defined in the appended Claim 1.

According to a second aspect of the invention, there is provided a display device as defined in the appended Claim 28.

Preferred embodiments of the invention are defined in the other appended Claims.

Because substantially all of the light emitted by the light source is incident upon the display, the brightness of the display is increased and hence the efficiency of the device is improved. A further advantage is that the illumination system is relatively compact.

The invention will further be described by way of example with reference to the accompanying drawings, in which like reference numerals denote like parts, and in which:-

Figure 1 is a diagrammatic view of an illumination system constituting a first embodiment of the invention;

Figure 2 is a diagrammatic view of an illumination system constituting a second embodiment of the invention;

Figure 3 is a view similar to Figure 1 illustrating a modification of the first embodiment;

Figure 4 is a view similar to Figure 2 illustrating a modification of the second embodiment; and

Figure 5 is a diagrammatic view illustrating a modification of the embodiments shown in Figures 1 to 4.

The illumination system illustrated in Figure 1 comprises a light source 10 consisting of an array of fluorescent tubes, a "serpentine" tube or one or more flat fluorescent lamps as described in US 4978888 arranged to emit white light having components falling within, say, three wavelength bands of, say, 20 nm width, the wavelength bands comprising a red wavelength band centred on approximately 610 nm, a green wavelength band centre on approximately 540 nm and a blue wavelength band centred on approximately 450 nm. A reflector 12 is provided behind the light source 10 in order to direct light emitted thereby towards a liquid crystal display device. The light is then incident upon a circular polariser 16 which comprises a linear polariser which absorbs one polarisation of light whilst transmitting the orthogonal polarisation, and a quarter wave plate which converts the plane polarised light incident thereon into circularly polarised light. Since the light incident upon the quarter wave plate is linearly polarised, all of the circularly polarised light transmitted thereby is of the same handedness, for example left-handed circularly polarised light.

The circularly polarised light transmitted by the circular polariser 16 is incident upon a cholesteric filter 18

which comprises a first layer 20 and a second layer 22. The cholesteric filter 18 is preferably provided between the substrates of the liquid crystal display device. The first and second layers 20, 22 each comprise patterned cholesteric liquid crystal polymer films which are patterned so as to include portions which reflect red light, transmitting the blue and green components, portions which reflect blue light transmitting the red and green light components, and portions which reflect the green light, transmitting the red and blue components, the letters R, G and B in Figure 1 denoting the colour of the light reflected by each portion. As shown in Figure 1, the portions of the first and second layers 20, 22 are out of alignment with one another, so that, for example, the blue and green light transmitted by one of the portions of the first layer 20 is incident upon a portion of the second layer 22 which reflects blue light, transmitting only the green component (the red component having been reflected by the first layer), and a portion of the second layer 22 which reflects green light, transmitting only the blue component. Thus, each region of the filter 18 transmits only one of the three wavelengths, the other two wavelengths being reflected.

The light which is reflected by the filter 18 returns through the circular polariser 16 which converts the left-handed circularly polarised light into linearly polarised light which is reflected by the reflector 12, and returns through the circular polariser 16 to be incident upon the filter 18 once more. Reflectors 24 and 26 are arranged to substantially prevent light escaping from the sides of the illumination system. Any component of the light which is again reflected by the filter 18 will once more be reflected by the reflector 12, the light being repeatedly reflected by the reflector 12 and filter 18 until the light is incident upon a region of the filter 18 which transmits light of that wavelength band.

In use, the liquid crystal layer of the liquid crystal display is positioned adjacent the filter 18, possibly separated therefrom by additional layers, such as the display's electrodes and/or alignment layers, each pixel of the display being aligned with a respective region of the filter 18 so as to receive only one colour of light. By controlling the amount of red, green and blue light transmitted by the display by controlling the state of the liquid crystal in each pixel, a full colour display can be achieved.

The illumination system illustrated in Figure 2 is similar to that illustrated in Figure 1 but is an edgelit system rather than a backlit system as shown in Figure 1. Rather than using an array of fluorescent tubes or lamps, a single fluorescent tube or lamp is used, a reflector 12, for example a metallic mirror, being provided behind the source 10 to direct the light emitted therefrom towards a lightguide 34. A reflector 30, for example a metallic mirror or microprism array, is arranged to direct the light out of the lightguide 34 towards a circular polariser 16 as described with reference to Figure 1. In this embodiment, the light reflected by the filter 18 will ideally not be incident upon the reflector 12 and the fluorescent lamp, the reflector 30 being arranged to reflect the light back through the circular polariser towards the filter 18. Operation of this device is as described above.

The embodiments illustrated in Figures 3 and 4 differ from those illustrated in Figures 1 and 2 in that the circular polariser 16 illustrated in the embodiments of Figures 1 and 2 is replaced by a cholesteric mirror stack 32. As an alternative to the stack 32, a broadband polariser of the type disclosed in EP 0 606 940 may be used. The stack 32 is arranged to transmit only left-handed circularly polarised light. Any right-handed circularly polarised light incident on the stack 32 is reflected and, on being reflected by the reflector 12 in the embodiment of Figure 3 or by the reflector 30 in the embodiment of Figure 4, the polarisation state of this light is reversed and hence it will be transmitted by the stack 32 on returning from the reflector 12 or 30.

The light transmitted by the stack 32 is incident upon the filter 18 where, as described previously, certain components of the light are transmitted, other components being reflected by the filter 18. The reflected components return towards and are transmitted by the stack 32, after which the light is incident upon the reflector 12 or 30. On reflection by the reflector 12 or 30, the left-handed circularly polarised light is converted to right-handed circularly polarised light which is reflected at the stack 32 to be incident once more upon the reflector 12 or 30. The right-handed circularly polarised light is converted to left-handed circularly polarised light on reflection at the reflector 12 or 30, and so will be able to pass through the stack 32.

The mirror stack 32 is arranged to include a layer which reflects light of the red band, a layer which reflects light of the blue band, and a layer which reflects light of the green band.

In the embodiments illustrated in Figures 3 and 4, the cholesteric mirror stack 32 is arranged to reflect right-handed circularly polarised light while the filter 18 is arranged to reflect left-handed circularly polarised light. Alternatively, the stack 32 and filter 18 may be arranged to reflect left-handed and right-handed circularly polarised light, respectively. As a further alternative, the stack 32 and filter 18 may be arranged to reflect the same handedness of circularly polarised light, a half wave plate being provided between the stack 32 and filter 18 to convert the polarisation of the light from one handedness to the opposite handedness.

In use, each of the above described illumination systems is disposed adjacent, a liquid crystal display device. Alternatively and more preferably, the filter 18 is integral with the liquid crystal display device. The filter 18 is disposed as close as possible to a liquid crystal layer of the display device in order to minimise cross-talk between pixels of different colours. It has been found that a cholesteric film of thickness approximately 10 μm can reflect substantially all of the light of one colour and handedness. The total thickness of the filter 18

is therefore approximately 20 μm. If any light of the incorrect colour is transmitted by the first and second layers 20, 22, such light could be absorbed using an array of colour filters arranged to absorb light having a wavelength falling outside a predetermined band. Since only a small amount of light of the incorrect colour is likely to pass through the filter 18, the amount of light being absorbed by such colour filters will be small. The efficiency of the device with therefore not be substantially reduced. The provision of such absorbing colour filters furthers reduces problems associated with light from outside the system being reflected by the cholesteric filter.

In order to produce a ± 60° field of view, the size of each portion of the layers 20, 22 must be at least 70 μm, and hence each pixel of the display is at least 35 μm.

The angular acceptance bandwidth of a single pitch cholesteric liquid crystal material is typically ±20°. This is less than the typical angular field of view of a liquid crystal display. One technique for increasing the bandwidth of the cholesteric material is to provide a plurality of different pitches in each portion of material, for example, where a thermochromic material is used, by varying the temperature of the material while applying ultraviolet light to fix the material. Alternatively, a more collimated light source may be used, the light emitted thereby falling within the angular acceptance bandwidth of the material. Where such a light source is used, any diffuser placed before the cholesteric filter is preferably relatively weak, the light remaining within the angular acceptance bandwidth of the material. In order to increase the angular view of the device, a relatively strong diffuser may be positioned between the filter 18 and the viewing positions. If such a diffuser is provided between the filter 18 and the liquid crystal layer, the diffuser should be a polarisation preserving diffuser. However, a polarisation preserving type of diffuser is not required if the diffuser is provided between the final polariser and the viewing positions.

If the liquid crystal device requires linearly polarised light rather than circularly polarised light as is transmitted by the embodiments illustrated in Figures 1 to 4, then a patterned quarter wave plate or broadband quarter wave plate can be provided after the filter 18. Such a patterned quarter wave plate may be fabricated from a polymer which has been subjected to ultraviolet light to induce birefringence therein. Alternatively, an aligned liquid crystal polymer film may be used.

In a further modification, the circular polariser 16 of the embodiments of Figures 1 and 2 may be replaced by a polarisation selective holographic element which may be arranged to transmit circularly polarised light of a particular handedness, or to transmit plane polarised light which is converted to circularly polarised light by a quarter wave plate. The light which is not transmitted by the polarisation selective holographic element is reflected, the polarisation state is changed, and the light is returned to and transmitted by the polarisation selective holographic element.

A further factor which results in a reduction in the amount of light passing through an active matrix liquid crystal device is that light incident upon the thin film transistors (TFT's), the wiring and the black matrix (an absorber necessary for achieving high contrast) is absorbed by these elements of the liquid crystal display device, and so does not contribute to illumination of the display. Such absorption of light results in a 30 to 50% reduction in light transmitted by the liquid crystal display. In order to reduce the amount of light lost in this way, an array of reflective material 36 and quarter wave retarders 38 is applied to the surface of the filter 18 facing the light source 10 (as shown in Figure 5) so that the quarter wave retarders 38 are disposed in front of the reflective material 36 relative to the direction of light incident upon the latter. The reflective material 36 is positioned so as to reflect light which would otherwise be incident upon the TFT's, wiring, and the black matrix. The light incident upon the reflective material 36 is reflected back towards the light source 10 together with the light which is reflected by the filter 18. Since the light reflected by the reflective material 36 is ultimately able to pass through the filter 18, and hence to pass through the liquid crystal device, the provision of the reflective material 36 increases the efficiency of the display.

In Figure 5, left handed circularly polarized light is incident on the quarter wave retarder 38, and is converted to linearly polarized light by passing therethrough. Next, the linearly polarized light is incident upon the reflective material 36, and is reflected therefrom so as to enter the quarter wave retarder 38 again. The quarter wave retarder 38 converts the linearly polarized light from the reflective material 36 to left handed circularly polarized light. Therefore, the handedness of the circularly polarized light passing through the quarter wave retarder 38 from the reflective material 26 is the same as that of the circularly polarized light passing through the quarter wave retarder 38 towards the reflective material 36. On the other hand, if the quarter wave retarders 38 were not present, the left handed circularly polarized light would be incident on the reflective material 36 and would then be converted to right handed circularly polarized light by being reflected therefrom.

Although in the described embodiments the filter 18 comprises two layers, the filter may include more than two layers, each portion of each layer reflecting a single relatively small band of wavelengths. This is of particular importance where the light source does not emit three well defined bands of light. Further, the filter may not comprise well defined layers of cholesteric material, the wavelength reflected by each region of the filter being dependent upon the distance from the surface of the filte for example.

In a modification to the above described embodiment, the first and second layers are not offset from one another, all of one portion of the first layer being aligned with all of a corresponding portion of the second layer. In use, the modification operates in exactly the same

manner as described above, the pixel size of the liquid crystal display device in this case being substantially equal to that of each portion of each layer of the filter.

The patterned layers 20, 22 of the filter 18 may be fabricated by masking a substrate and applying the cholesteric material to apertures provided ir the mask, or by masking certain parts of a cholesteric layer and removin or altering the properties of the exposed parts. The filter 18 may therefore be fabricated by using screen printing, spinning, dipping, optical lithography or like methods. Where a thermochromic cholesteric material is used, the temperature of the material may be adjusted until the desired reflection/transmission properties have been achieved, the properties then being fixed, for example by ultraviolet polymerisation of the material, or by ultraviolet crosslinking, the method being dependent upon the material used.

Claims

1. An illumination system comprising a polarised light source (10, 12, 16, 30, 32, 34) arranged to transmit circularly polarised light, characterised by a cholesteric filter (18) having a first region arranged to transmit circularly polarised light of wavelength falling within a first predetermined band and to reflect light having a wavelength falling outside of the first band, and a second region arranged to transmit circularly polarised light of a wavelength falling within a second predetermined band and to reflect light having a wavelength falling outside of the second band, and a reflector (12, 30) arranged to return the light reflected by the cholesteric filter (18) towards the cholesteric filter (18).

2. An illumination system as claimed in Claim 1, characterised in that the reflector (12, 30) is arranged to return the light reflected by the cholesteric filter (18) towards a second region thereof arranged to transmit circularly polarised light of a wavelength falling within a second predetermined band different to the first band and to reflect light having a wavelength falling outside of the second band.

3. An illumination system as claimed in Claim 1, characterised in that the cholesteric filter (18) further comprises at least one further region arranged to transmit circularly polarised light of wavelength falling within a respective predetermined band different to the first and second bands, and to reflect light of wavelength falling outside of that band.

4. An illumination system as claimed in any one of the preceding claims, characterised in that the reflector (12, 30) and cholesteric filter (18) are arranged to repeatedly reflect light therebetween until the light is incident upon a region of the cholesteric filter (18) which transmits light of that wavelength.

5. An illumination system as claimed in any one of the preceding claims, characterised in that each region of the cholesteric filter (18) comprises a plurality of layers (20, 22), each layer being arranged to transmit circularly polarised light of wavelength falling outside of a predetermined range and to reflect circularly polarised light of wavelength falling within the predetermined range, the band of wavelengths transmitted by all of the layers (20, 22) defining the predetermined band for that region.

6. An illumination system as claimed in Claim 5, characterised in that each layer (20, 22) comprises a film superimposed upon an adjacent layer.

7. An illumination system as claimed in Claim 5 or 6, characterised in that the cholesteric filter (18) comprises two layers (20, 22).

8. An illumination system as claimed in any one of Claims 5 to 7, characterised in that each layer (20, 22) of the cholesteric filter (18) comprises a plurality of portions (R, G, B), each portion (R, G, B) being arranged to transmit circularly polarised light of wavelength falling outside of a respective range and to reflect circularly polarised light of wavelength falling within the predetermined range.

9. An illumination system as claimed in Claim 8, characterised in that the portions (R, G, B) of the layer (20, 22) are arranged to overlap with one another such that each region of the cholesteric filter (18) is defined by an overlapping part of the portions (R, G, B) of the layers.

10. An illumination system as claimed in any one of the preceding claims, characterised in that the cholesteric filter (18) comprises a cholesteric liquid crystal polymer.

11. An illumination system as claimed in any one of the preceding claims, characterised in that the light source (10, 12, 16, 30, 32, 34) comprises a fluorescent source (10) arranged to emit light falling within substantially distinct wavelength bands.

12. An illumination system as claimed in Claim 11, characterised in that at least one of the distinct wavelength bands is within the first predetermined band of the cholesteric filter (18).

13. An illumination system as claimed in any one of the preceding claims, characterised in that the light source (10, 12, 16, 30, 32, 34) comprises a circular polariser (16, 32).

14. An illumination system as claimed in Claim 13, characterised in that the circular polariser is an absorbing polariser (16).

15. An illumination system as claimed in Claim 14, characterised in that absorbing polariser (16) comprises an absorbing plane polariser and a quarter wave plate.

16. An illumination system as claimed in Claim 13, characterised in that the circular polariser is a reflecting polariser (32).

17. An illumination systems as claimed in Claim 16, characterised in that the reflecting polariser comprises a cholesteric mirror (32) arranged to transmit circularly polarised light of a first handedness and to reflect circularly polarised light of the opposite handedness.

18. An illumination system as claimed in Claim 17, characterised in that the cholesteric mirror (32) includes a first layer arranged to reflect light of the first wavelength band and a second layer arranged to reflect light of the second wavelength band.

19. An illumination system as claimed in Claim 18, characterised in that the cholesteric mirror (18) further comprises at least one additional layers, the or each additional layer being arranged to reflect light of wavelength falling within a respective additional predetermined band.

20. An illumination system as claimed in Claim 16, characterised in that the reflecting polariser comprises a polarisation selective holographic element.

21. An illumination system as claimed in Claim 20, characterised in that the holographic element is arranged to transmit circularly polarised light.

22. An illumination system as claimed in Claim 20, characterised in that the holographic element is arranged to transmit plane polarised light and in that the polarised light source (10, 12, 16, 30, 32, 34) further comprises a quarter wave plate.

23. An illumination system as claimed in any one of Claims 13 to 22, characterised in that the handedness of the circularly polarised light transmitted by the circular polariser is the same as that of the light transmitted by the cholesteric filter (18).

24. An illumination system as claimed in any one of Claims 13 to 22, characterised in that the handedness of the circularly polarised light transmitted by the circular polariser is opposite that of the light transmitted by the cholesteric filter (18).

25. An illumination system as claimed in Claim 24, characterised by means for converting the circularly polarised light from one handedness to the opposite handedness.

26. An illumination system as claimed in Claim 25, characterised in that the converting means comprises a half wave plate.

27. An illumination system as claimed in any one of the preceding claims, characterised in that the reflector (12, 30) is arranged to convert the polarisation of the light incident thereon from one handedness to the opposite handedness.

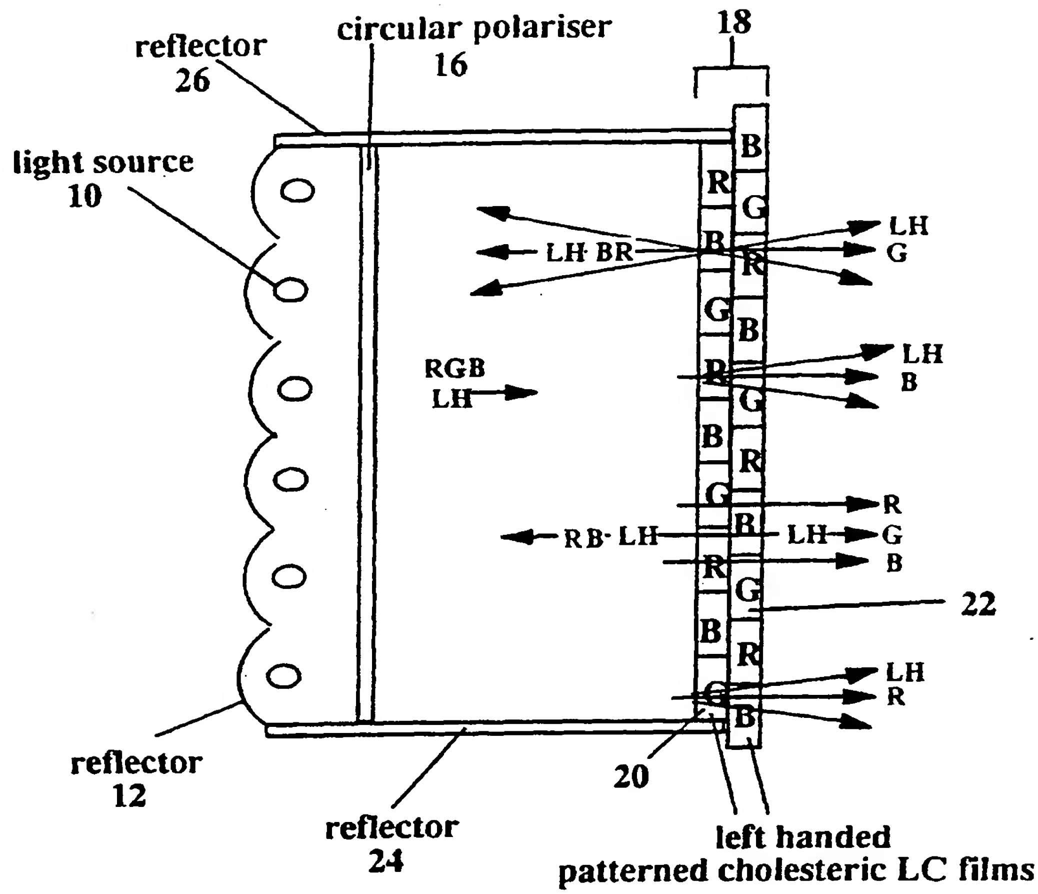
28. A display device comprising an illumination system as claimed in any one of the preceding claims and a spatial light modulator.

29. A display device as claimed in Claim 28, characterised in that the spatial light modulator comprises a liquid crystal display.

30. A display device as claimed in Claim 29, characterised in that the cholesteric filter (18) is integral with the liquid crystal display.

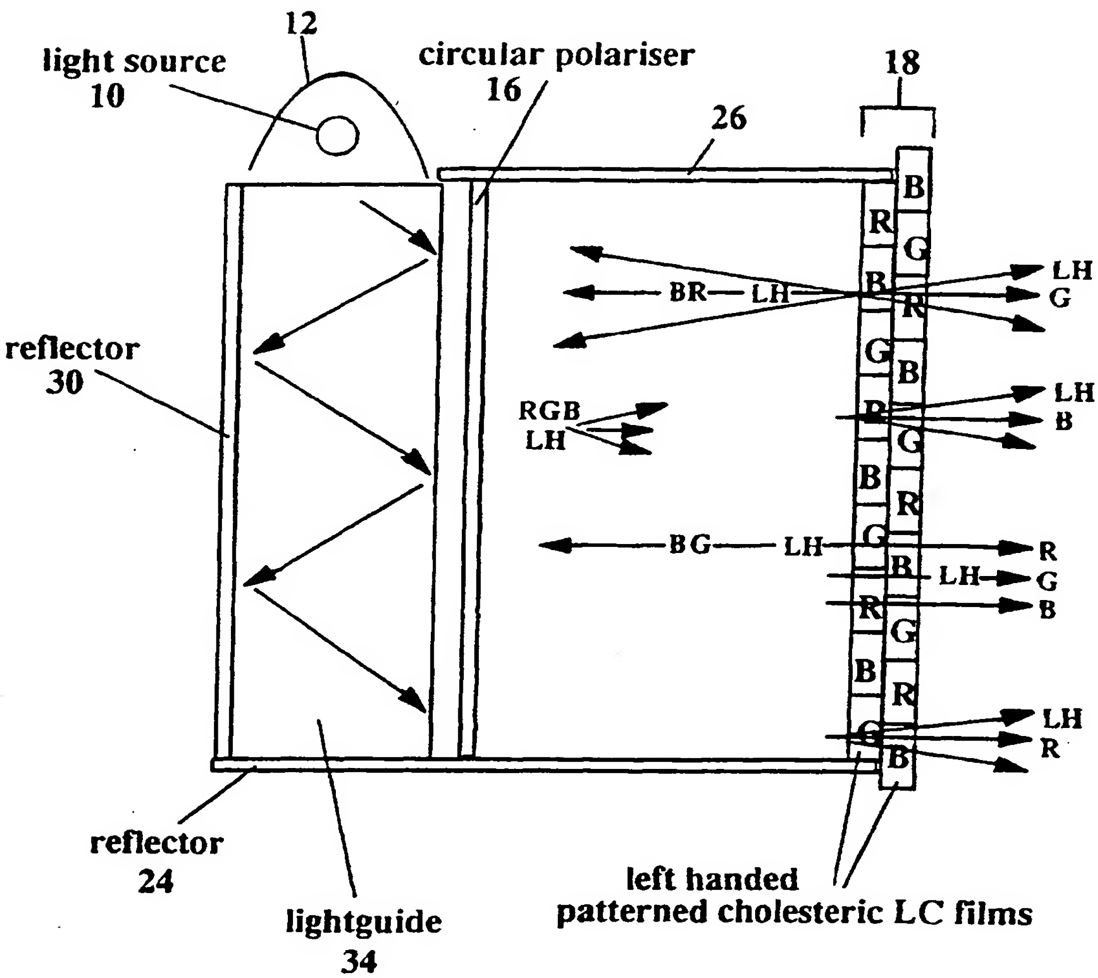
31. A display device as claimed in any one of Claim 29 or 30, characterised by reflective material (36) arranged to reflect light away from non-transmissive parts of the liquid crystal display.

32. A display device as claimed in Claim 31, characterised by quarter wave retarders (38) disposed in front of the reflective material (36) relative to the direction of light incident upon the latter so that, in use, such light passes through the quarter wave retarders (38) before and after reflection from the reflective material (36).



reflector
26
circular polariser
16
18
light source
10
B
R
G
LH
B
G
LH BR
R
G
B
RGB
LH
LH
B
G
B
R
G
R
RB LH
B
LH
G
R
B
G
22
B
R
LH
R
G
B
reflector
12
20
reflector
24
left handed
patterned cholesteric LC films

Figure 1


12
light source
10
circular polariser
16
18
26
reflector
30
RGB
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LH
LH
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B
R
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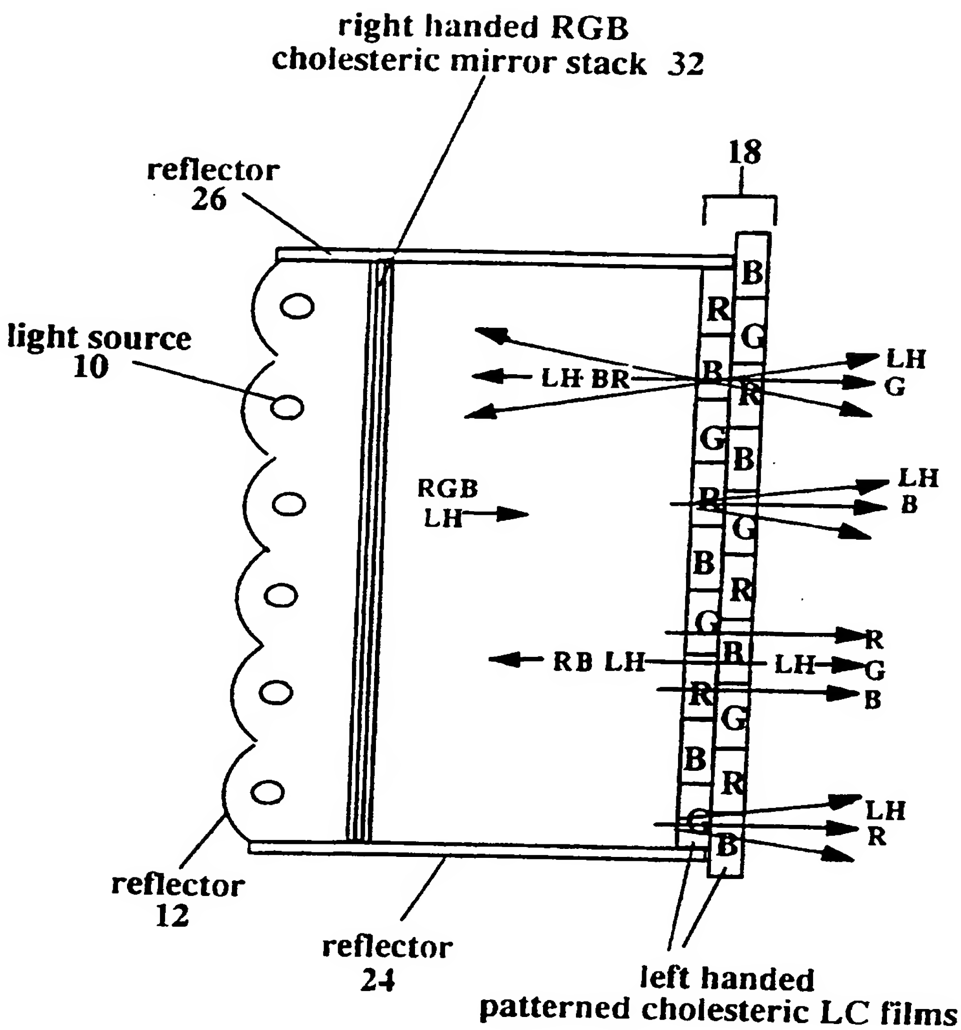
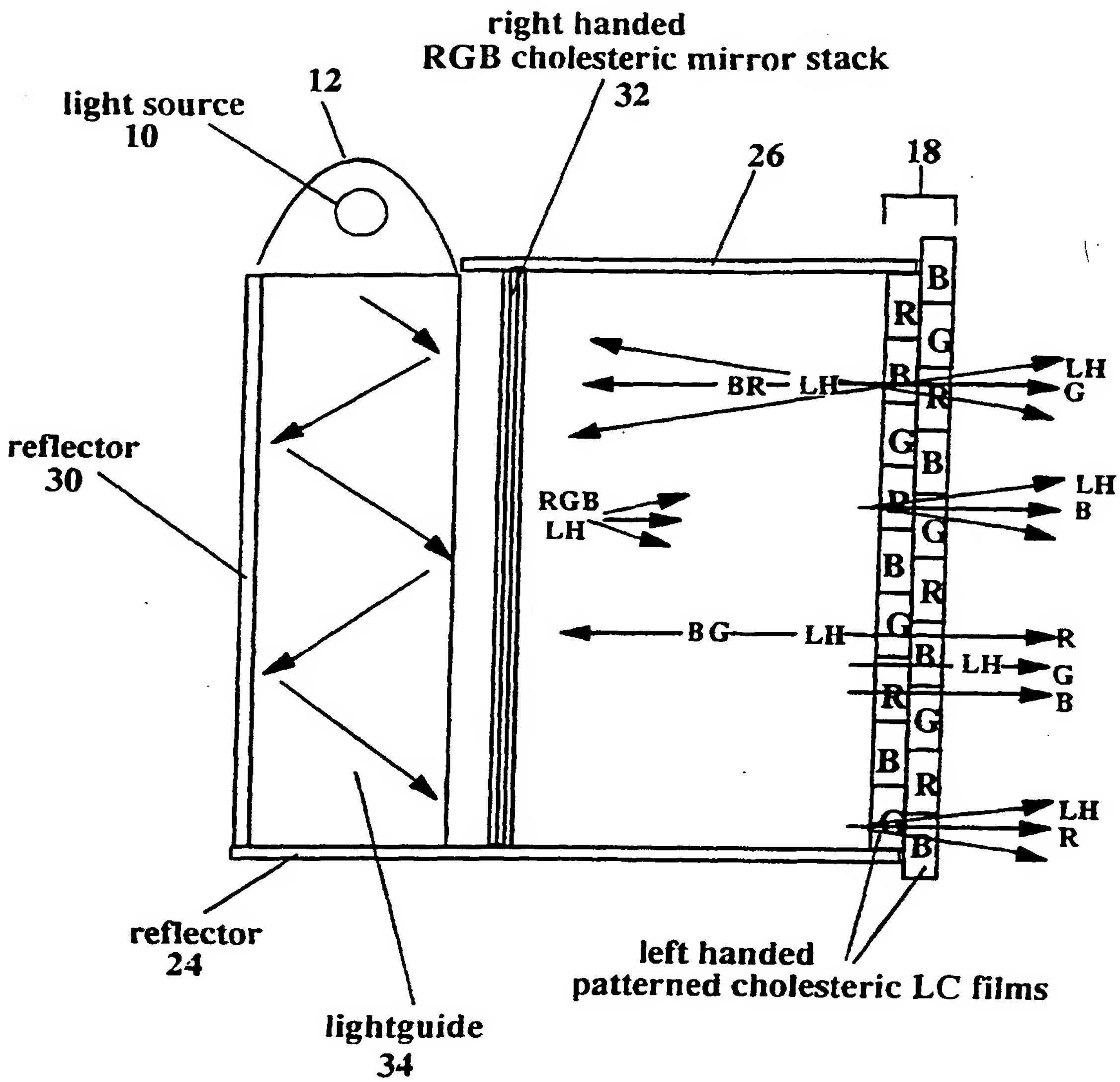
G
B
LH
R
reflector
24
lightguide
34
left handed
patterned cholesteric LC films

Figure 2



right handed RGB
cholesteric mirror stack 32
reflector
26
18
light source
10
LH BR
RGB
LH
RB LH
LH
LH
G
LH
B
R
G
B
LH
R
reflector
12
reflector
24
left handed
patterned cholesteric LC films

Figure 3


right handed
RGB cholesteric mirror stack
32
12
light source
10
26
18
reflector
30
BR
LH
RGB
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B
R
LH
G
B
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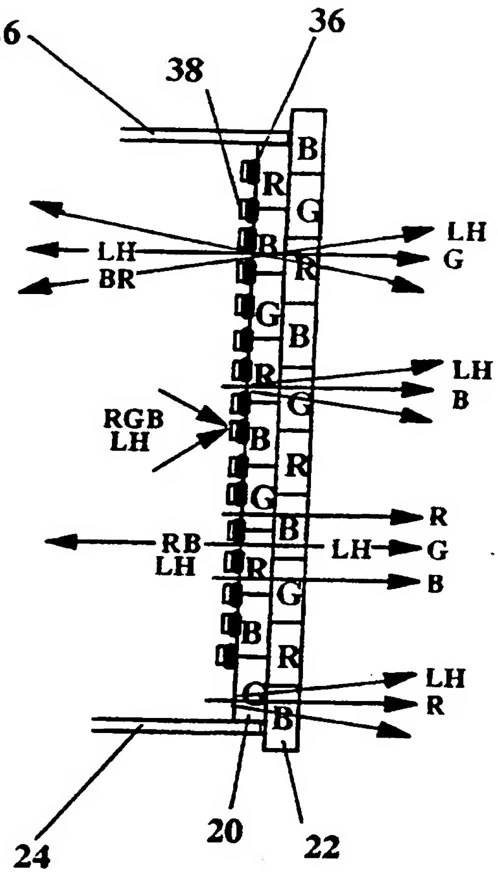
R
B
R
G
reflector
24
lightguide
34
left handed
patterned cholesteric LC films

Figure 4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36
38
B
R
G
LH
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BR
B
R
G
B
LH
B
RGB
LH
R
R
RB
LH
G
B
LH
G
B
R
G
B
R
LH
R
24
20
22

Figure 5